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The Virginia V-Notch Weir

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PREFACE

This is a report of the development and testing of an idea originated in Virginia during a field study relating to the use of highway culverts for runoff measurement. A number of culverts were examined and found to be well suited for the measurement of the higher runoff rates from the watersheds. However, for the lower flow rates, the culvert openings lacked the needed sensitivity. Since a relatively large percentage of the total flow probably occurs at the lower rates, an auxiliary device was needed to measure low flows with the desired degree of accuracy. The Villemonte weir sill used in Oklahoma would not completely satisfy the need because of certain minimum head limitations. Also, the continuous flow would make installation of weir sills within the culvert quite a chore whereas a sill outside the culvert entrance would be easier to construct. These considerations led to the idea of placing a V-notch weir at or near the culvert entrance. For easy reference, the device has been named the "Virginia V-notch."

Prepared by

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THE VIRGINIA V-NOTCH WEIR

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INTRODUCTION

The Virginia V-notch weir is a standard V-notch placed near the entrance to a highway culvert. The two are tandem arranged so the flow passes over the one to enter the other. Water stage is controlled by the V-notch during small flows. As the flow increases, the control gradually passes to the culvert entrance. The combination of the V-notch and culvert entrance is the equivalent of a single rate-measuring structure, since it has one head-discharge relationship. Considerable cost saving is achieved by using an existing highway culvert for the primary meter of flow rate. The auxiliary V-notch is relatively small and inexpensive to build and, with the culvert, provides a measuring station of satisfactory accuracy throughout the range of flows. Another advantage is that under specified conditions, a standard rating curve would apply and special calibration would not be needed. An essential characteristic of the culvert is that the control section be at the entrance. If the water stage at the entry were controlled by high water below or by culvert-barrel friction, this method could not be used--at least, not with a single head gage.

One of the objections to this arrangement is the reduction of culvert flow capacity because of entrance obstruction by the V-notch. The higher the weir notch and the closer it is to the entrance, the greater the reduction. An important objective of these exploratory studies was to determine the reduction in culvert flow capacity for various combinations of notch height and distance from the entrance. Also sought were the answers to other questions: Would the arrangement provide a satisfactory measuring device? Would it have stable rating characteristics, that is, would the rating be the same for rising and falling stages and would it neither pulsate nor surge? Model studies were undertaken to find the answers.

The tests were made at the Outdoor Hydraulic Laboratory, Stillwater, Okla. This is a research facility of the Watershed Technology Research Branch, Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture. The junior author conducted the tests, and analyzed the data, under the general direction of the Project Supervisor.

[1]Project supervisor and hydraulic engineer, Soil and Water Conservation Research Division, Agricultural Research Service; located at Stillwater, Okla.

THE MODEL

A one-tenth size replica of one of the culverts previously employed in the Stillwater, Okla., runoff studies was used for these tests. The prototype is a twin-barrel structure, each tube being 4 feet deep and 8 feet wide. In the model, various V-notch weirs were placed on the culvert apron and tested. Figure 1 is a photograph of the model with a weir in place. In this particular case, the prototype V-notch would be 3 inches high and 4 feet upstream from the culvert entrance. A twin V-notch was used to match the two culvert openings. Flow through a single V-notch, centered on the culvert, would have been subject to disturbance by the center wall.

Figure 1. General view of the model with a weir in place. These notches would be 3 inches high and 4 feet upstream from the culvert entrance in the prototype.

The models of the culvert and V-notches were made of redwood and varnished. Dimension changes during testing were negligible. The approach topography was molded in concrete. All test flows were measured by a calbrated orifice meter or a 0.4 HS flume. Heads on the notches were measured by a point gage operating in a well connected to the gage well upstream of the culvert. The gage well can be seen at left center in figure 1.

THE TESTS

Six combinations of notch heights and distance settings from culvert entrance were tested. These combinations are given below:

Prototype height (Y)	Prototype distance upstream (X)
Inches	Feet
3	1.5, 3, 4
6	3, 4
12	4

A sketch of the culvert entrance and the notch is shown in figure 2.

The 6-inch-high prototype notch, 3-feet upstream, was selected for more exhaustive testing. This required 23 model tests of prototype flows ranging from 0.46 c.f.s. to 588 c.f.s.

EXPERIMENTAL RESULTS

A plot of the resulting head-discharge curve is shown in figure 3. A detailed examination of this rating curve leads to an understanding of the hydraulic behavior of the combination in the prototype.

For heads up to 0.80 foot, the flow is contained wholly within the V-notches. A simple power function defines the rating in this range. The equation for one opening was found in these tests to be:

$$Q=2.90 \tan \frac{\theta}{2} H^{2.94}$$

Where Q is discharge rate in c.f.s.
H is the head above the V-notch
θ is angle within the V-notch, in this case $\tan \frac{\theta}{2} = 5$

The information given by Harrold and Krimgold[2] indicates the rating curve for a 5:1 V-notch of similar crest shape to be:

$$Q=2.65 \tan \frac{\theta}{2} H^{2.58}$$

The agreement between the two ratings is not exact. In partial explanation of this difference, it should be noted that Harrold and Krimgold's equation is for heads greater than 1 foot but the tests under discussion are for heads less than 1 foot. At a head of about 0.82 foot, these 2 equations give the same discharge and at a head of 0.50 foot the discharge observed for this notch is about 15 percent less than that computed by Harrold and Krimgold's equation. So, the difference between the two equations is not great in the range of application.

When the head exceeds 0.80 foot, flow starts over the level crest sections at the center and the 2 sides. This sudden increase in crest length results in a slight flattening of the curve at a head of about 1 foot. As the head is increased further, the curve steepens again. This is attributed initially to the converging sidewalls, which constrict the flow section as the water passes over the weir, and to the fact that the weir length no longer increases with increased depth. When the head reaches about 2.35 feet, the culvert entrance begins to cause a backwater effect on the weir and from here on up the control gradually passes from the weir to the culvert. A small break in the rating occurred at a head of about 3.40 feet. This is attributed to the deep fillets or haunches at the center wall of the culvert. Finally, there is a major change in the slope of the curve at a head of 4.70 feet. At this point, the flow changes from critical depth control by the culvert entrance to orifice or sluice gate flow, which starts with the complete submergence of the entrance. Thus, a ready physical explanation is found for the various slopes of the plot.

The shape of the curve is unimportant as long as it is a constant and the structure has the required degree of sensitivity over the flow range. These conditions are met by the Virginia V-notch weir and culvert combination. A few tests were made on the culvert without the V-notch weir in place. These were limited to heads in excess of 3.5 feet, since the higher flows were of more value in comparisons of the capacity of the culvert with V-notches and its capacity without them.

[2]Harrold, L. L., and Krimgold, D. B. *Devices for Measuring Rates and Amounts of Runoff;* U. S. Dept. of Agr., Soil Conservation Service Technical Paper 51, 42 pp. July 1943, revised May 1948.

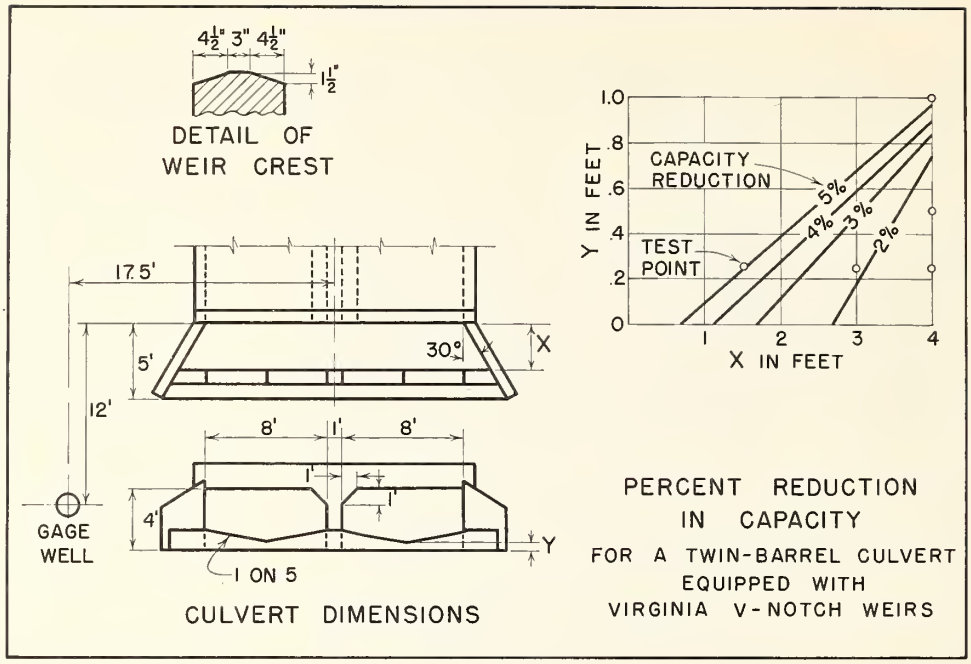

Figure 2. Reduction of flow capacity for a twin-barrel culvert caused by a pair of V-notch weirs placed on the apron. The reduction is expressed in percent and is calculated for a water depth of 5.5 feet above the culvert apron.

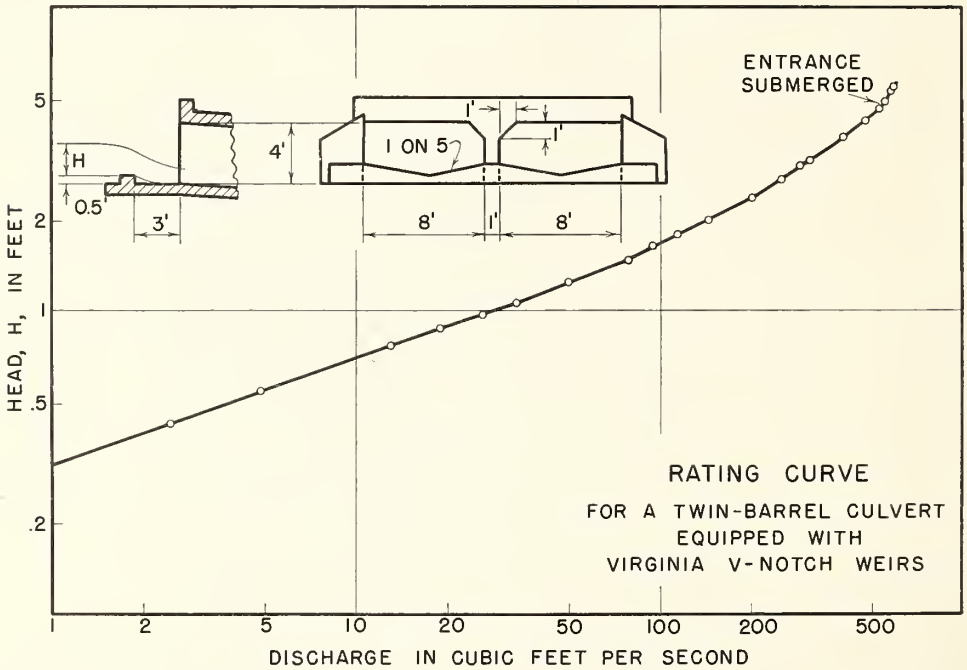

Figure 3. Rating curve for a twin-barrel culvert equipped with Virginia V-notch weirs. Point of head measurement is 12 feet upstream from culvert entrance.

The effect of the V-notch on the culvert capacity was determined by comparing discharge rates, with and without notches, for a water surface elevation 5.5 feet above the culvert floor at the entrance. At this head, the flow was in the orifice range for all combinations tested, so the comparisons are on a like basis. Reduction of culvert flow capacity, expressed in percent, caused by Virginia V-notch weirs are given below:

Height of notch, Y	Distance from notch to culvert entrance, X	Capacity reduction
Feet	Feet	Percent
0.25	1.5	5.11
.25	3	2.07
.25	4	1.52
.50	3	3.07
.50	4	1.26
1.00	4	5.55

The relationship between capacity reduction and the height of notch and the distance from notch to culvert entrance is poorly defined in the tabular matter above, because only a few points are available. Yet these percentage figures, when plotted against the corresponding dimensions X and Y, would seem to fit into a family of curves. A relationship is definitely shown, figure 2, by a family of straight lines.

The use of the diagram of figure 2 is illustrated by an example: Assume that a V-notch weir is to be installed and that a 5-percent reduction in flow capacity can be tolerated. If a notch height of 0.25 foot is selected, it should be no closer to the culvert entrance than 1.55 feet. If a notch 0.5 foot high is desired, the distance must be at least 2.40 feet. This diagram applies only to culverts geometrically similar to the one tested. Despite this severe limitation, it is thought that the diagram has some usefulness in that it will aid in preliminary selections of V-notch dimensions.

All tests were made with the V-notch projecting above the apron. In the field, deposition would likely fill the approach channel to the level of the notch. The rating of the notch would be affected, but the culvert capacity would be about the same as previously determined.

SUMMARY

Tests were made to determine the hydraulic characteristics of V-notch weirs placed on a culvert entrance apron. The V-notch weir and culvert combined made a satisfactory runoff measuring station. The culvert itself is a ready-made measuring device satisfactory for all but the smaller flows. Adding a V-notch weir provides the sensitivity necessary in the low-flow range. Laboratory tests showed the rating to be stable, that is, only one discharge rate occurs for a given head. The presence of the V-notch reduced the capacity of the culvert, the amount depending upon the height and distance from the entrance. This reduction, for the more practical combinations of height and distance, was 5 percent or less.